Agriculture, Ecosystems and Environment 129 (2009) 482–490

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Runoff quality evaluations of continuous and rotational over-wintering systems for beef cows

Lloyd B. Owens *, Martin J. Shipitalo

USDA-ARS, North Appalachian Experimental Watershed, P.O. Box 488, Coshocton, OH, USA

ARTICLE INFO

Article history:
Received 17 April 2008
Received in revised form 5 November 2008
Accepted 6 November 2008
Available online 17 December 2008

Keywords:
Vegetative cover
Surface runoff
Sediment loss
Surface N loss

ABSTRACT

Over-wintering cattle out of doors can be detrimental to the areas that cattle occupy and cause increased runoff, sediment loss, and nutrient transport. Two systems of over-wintering cattle were evaluated for their environmental impacts over a 12-year period, November 1974–October 1986. In one system, beef cows were moved on 6–7 day intervals among four pastures during the summer growing season (May–October), rotated through hayed areas to eat fall regrowth, and rotated through these areas to feed on the hay made in those areas. In another system, cows were rotated weekly during summer and then fed hay in one winter area during the dormant season (November–April). Vegetative cover in the continuous wintering area frequently decreased to less than 50% by late winter/early spring while it remained at or near 100% in the rotational system. Monthly runoff averages were greater from the continuous wintering system than the rotational wintering system in 9 out of 12 months (annual runoff of 120.4 and 37.5 mm, respectively). Sediment loss was also greater from the continuous system than the rotational wintering system (2.68 and 0.24 Mg ha^{-1} annual averages, respectively). Surface runoff losses of N were greater during the dormant season (13.2 and 6.7 kg N ha^{-1} annual averages for the continuous and rotational wintering systems, respectively) than the growing season (4.6 and 1.3 kg N ha^{-1} annual averages, respectively). Runoff, sediment, and N losses were less with this rotational wintering system than with the continuous occupancy wintering system, but the animal occupancy rate was also much greater in the continuous system compared with the rotational system (1497 and 1860 cow days ha^{-1} compared with 528 and 576 cow days ha^{-1}). Although a direct comparison cannot be made between these two systems because of differences in vegetation, stocking rate, and fertilization, the rotational wintering system that was evaluated appears to be sustainable. However, more land area per cow was necessary than with the continuous wintering system that was evaluated.

Published by Elsevier B.V.

1. Introduction

Various grazing systems have been studied for their impacts on surface water quality with emphasis on losses of sediment, phosphorus, and nitrogen. Numerous studies have shown that regularly grazed areas will have greater nutrient and sediment loss than ungrazed areas. For example, Doran et al. (1981) showed a 1.1–1.8-fold increase in nutrient loss (e.g. NH_4-N, NO_3-N, soluble P, and total P) in surface runoff from a grazed pasture compared with an ungrazed area. Going from ungrazed management to unimproved grazing management, i.e. continuous grazing with no nutrient inputs, Owens et al. (1989) indicated that the presence of cattle caused an increase in sediment, NO_3-N, NH_4-N, and especially organic-N.

Many of the U.S. studies about the impacts of livestock on grazing lands have been conducted in the western U.S. Streambank stability with cattle grazing (Marlow et al., 1987; Renard, 1988; Marlow, 1988), soil property changes resulting from livestock grazing/trampling (Warren et al., 1986; Bauer et al., 1987), and changes in surface runoff and sediment loss following prescribed burning (Emmerich and Cox, 1994) are some of the topics which have been reported.

Even though the impacts of cattle grazing on surface runoff and soil loss in the humid, east central U.S. have not been widely studied, there was a study in Pennsylvania (Alderfer and Robinson, 1947) that reported high runoff rates from heavily grazed pastures compared with ungrazed areas. Poor vegetative cover was one of the factors to which they attributed the high runoff. Applying simulated rainfall to runoff plots with different grazing intensities in North Dakota, Hofmann and Ries (1991) found that percent bare ground was the most important factor explaining soil loss. As ground cover increased, soil sediment in runoff decreased. In separate studies on clay loam soils in Australia, Costin (1980) and

* Corresponding author.
E-mail address: lloyd.owens@ars.usda.gov (L.B. Owens).
Abbreviations: WS, watershed; Tot N, total N; Org N, organic N.

0167-8809/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.agee.2008.11.003

Lang (1979) reported that 70–75% ground cover was the critical threshold, above which runoff was slight and below which runoff increased rapidly. On deeply weathered, highly permeable soils in eastern Kenya, Zobisch (1993) reported that 40% grass cover was the critical level for that area, and below this level soil loss became a serious problem.

Research on nitrogen losses from grazed lands indicates that most of the losses occur by NO_3 leaching (Sharpley and Syers, 1979; Owens and Bonta, 2004; Owens et al., 1982, 1983; Ryden et al., 1984; Stout et al., 2000; Anger et al., 2002). In Northern Ireland, both organic N and inorganic N losses via subsurface drainage were measured from grazed plots in sandy clay loam soil (Watson et al., 2000a, 2000b). In an Australian study, Ridley et al. (2003) reported that soil types were a major factor in determining water and nutrient pathways. A soil with a low infiltration rate had surface runoff as the major pathway for water and nutrient losses, while a soil with a high infiltration rate had deep drainage as the major pathway for water and nutrient losses. Nevertheless, because surface runoff was not a major pathway of N loss in most pasture studies, surface N losses were often reported for the summer grazing period only and in terms of seasonal or annual losses (Owens and Bonta, 2004; Owens et al., 1982, 1983) rather than event-based losses. Information on runoff, sediment losses, and nutrient losses from pastures during winter months, especially on an event basis is quite limited.

Some of the winter research includes research in Oklahoma (Daniel, 2007) where stocker cattle, i.e. cattle being grown for feedlot finishing, grazed winter wheat pastures prior to being moved to feedlots. However, the major research focus was competition for soil water storage and subsequent crop water needs rather than environmental impacts. In New Zealand, McDowell (2006) studied phosphorus and sediment loss from areas that were winter cropped with *Brassica* spp. and grazed by dairy cattle. He found that by not allowing the cattle to "clear up" stream banks with limited grazing, there were minimal increases in P losses but suspended sediment load still increased by 75%. In eastern Ohio, Owens et al. (1997) reported much higher runoff and sediment losses from an area that was used for continuous winter feeding of beef cows (120 mm and 2.3 Mg ha^{-1} annual averages, respectively) than during winters when it was not a winter feeding area (14 mm and 0.15 Mg ha^{-1} annual averages, respectively). Owens and Shipitalo (2006) also reported P losses from pastures on an event basis, including the winter periods. Winter-grazing/feeding areas had 3–10 times more annual P loss in surface runoff than summer-grazing only areas.

In recent decades, there has been more emphasis on intensive grazing. In a review article, Bilotta et al. (2007) state that there is recognition that intensively managed grazing can have several detrimental environmental impacts. Treading from intensive grazing can damage soil structure, especially through compaction and pugging during wet conditions, and cause loss of vegetation through direct damage to the plants as well as indirectly damaging their rhizosphere. In their review of literature, Drewry et al. (2008) conclude that the impacts of compaction from treading can cause several detrimental effects but they may not be readily obvious. Large reductions in pasture yield can occur with animal treading, especially when soil is pugged during wet conditions. They report that there is very little information relating grazing animal treading on soil physical properties with pasture yield when plant damage and soil plugging are minimized.

One of the main purposes of winter management is to reach the next growing season. There is very limited information available on the environmental impacts of wintering systems, especially with regard to individual runoff events and their part in total nutrient and sediment loss. There were two, multi-year cattle wintering systems at the North Appalachian Experimental Watershed (NAEW). These were part of grazing systems where fertility level for summer grazing was one of the main thrusts rather than comparing wintering systems. Although direct comparisons cannot be made because of differences in fertility levels as well as stocking rates and vegetation, assessment of their respective environmental impacts can be done. Therefore, the objective of this paper was to use event-based data to evaluate two different systems for over-wintering beef cows in terms of vegetative cover, surface runoff, sediment loss, and N losses in surface runoff.

2. Materials and methods

This study was conducted at the NAEW near Coshocton, OH, USA (Fig. 1) from November 1974 through October 1986. Two rotationally grazed pasture management systems at high and medium fertility levels were used. A spring calving beef herd grazed four pastures during the summer in each system. The beef cows (*Bos taurus*) were in a pasture 5–7 days before being moved to the next pasture. Multiple grazing studies, varying N levels and sources, were conducted during this time period, and seasonal nutrient transports reported. During the dormant "wintering period" (November–April), cattle were rotated through paddocks in the high fertility system and kept continuously in one paddock in the medium fertility system. However, the environmental impacts of these wintering systems have not previously been the focus of analysis.

2.1. Rotational wintering system with high fertility

The cows were "wintered" during the 6-month dormant periods and were rotated through the four tall fescue (*Festuca arundinacea* Schreb.) pastures to graze fall regrowth. Then the cows were rotated through the same pastures again to use tall fescue hay that had been grown and stored in these pastures during the summer. Hay was fed as large, round bales (approximately 450 kg) in bale racks every 2 or 3 days depending on the quantity that the cows consumed. Because bare areas can develop around the feeding areas, the placement of the bales was scattered as uniformly as possible throughout the fields and watersheds to reduce spatial variability of vegetative cover. Percent cover was measured every 2 weeks by using a 2 m bar with holes on 5 cm intervals. Pins were dropped through these holes, and % cover was determined by the percentage of pins that touched vegetation or residue contrasted with bare soil.

This high fertility experimental area (24.0 ha) received 224 kg N ha^{-1} per year initially. Granular fertilizer and lime were broadcast applied according to soil tests to maintain topsoil pH of 6.5–7.0 and available P and K levels of 56 and 336 kg ha^{-1}, respectively.

This area was divided into eight pastures, four for summer rotational grazing on orchardgrass (*Dactylis glomerata* L.) during the growing season (May–October) and four for rotational wintering.

After 5 years, alfalfa (*Medicago sativa* L.) was interseeded into the grasses and no N fertilizer was added (Owens et al., 1994). Available P and K soil levels were maintained, 56 and 336 kg ha^{-1}, respectively. Fertilizer amounts and other management details were reported by Owens et al. (1998).

2.2. Continuous wintering system with medium fertility

The pasture system with the continuous wintering area (17.2 ha) received 56 kg N ha^{-1} per year initially. Granular fertilizer and lime were broadcast applied according to soil tests to maintain a topsoil pH of 6.0 and available P and K levels of 28 and

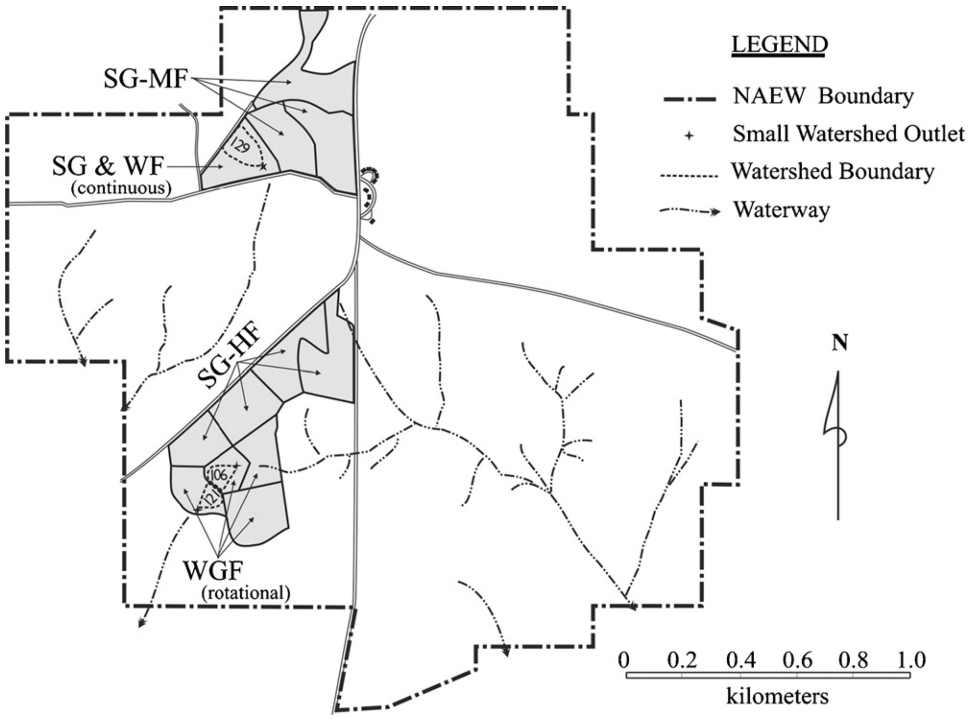

Fig. 1. The North Appalachian Experimental Watershed research station near Coshocton, OH (USA) showing the three wintering pasture watersheds used in the two management systems (WS 129; and WS 106 and WS 121). SG-MF = summer grazing-medium fertility; SG-HF = summer grazing-high fertility; SG & WF = summer grazing & winter feeding; WGF = winter grazing/feeding.

168 kg ha^{-1}, respectively. This area was divided into four pastures with predominant vegetation of orchardgrass and Kentucky bluegrass (*Poa pratensis* L.). Cows grazed all four pastures during the summer growing season but were moved to one pasture for wintering. They remained in this paddock continuously during the dormant period where they were fed hay, grown elsewhere on the station. Hay was fed as large, round bales in bale racks. As in the rotational wintering area, bales were fed throughout the field and watershed. Percent cover was determined in the same manner.

After 5 years the annual N fertilizer rate was increased to 168 kg ha^{-1} (Owens et al., 1992) except in wintering area where the annual contribution from hay was nearly 300 kg ha^{-1} (Owens et al., 1982). Available P and K soil levels were maintained, 28 and 168 kg ha^{-1}, respectively (Owens et al., 2003). Nine years after the beginning of the study, beginning with the 1983 growing season, the cow herd was increased from 25 to 30 cow-calf units for the remaining 3 years.

2.3. Watersheds, slopes, and soils

There are small watersheds (WS) in each wintering area, with berms to accentuate the natural contour breaks, for determining surface runoff. In the rotational wintering system, two paddocks (2.2 and 2.3 ha in area) had small watersheds (WS 106, 0.7 ha and WS 121, 0.6 ha), and the continuous wintering area (3.1 ha) had one small watershed (WS 129, 1.1 ha). There were watersheds in the summer areas also, but because the focus of this paper is to evaluate wintering systems, only the watersheds in wintering areas will be discussed.

The slopes of the rotational wintering areas ranged from 6 to 25% with an average of approximately 15%. The soils in this area (Rayne, Berks, and Dekalb series) are well-drained residual silt loams (Soil Taxonomy, Typic Dystrochrepts and Hapludults; FAO, Dystric Cambisols and Dystric Luvisols). Watershed 129 (continuous wintering area) slopes ranged from 12 to 25%, with an average of approximately 18%. Soils (Berks and Rayne) are well-drained residual silt loams. Soil, climate, geology, and geomorphology of both fertility areas and all of the watersheds were described in greater detail by Kelley et al. (1975).

2.4. Hydrologic measurements

Surface runoff from the watersheds was quantified using pre-calibrated 76-cm H-flumes housed within heated enclosures that permitted year-round measurements. The H-flumes measured the height of flow over time, from which the quantity of flow was calculated. Surface runoff water samples were collected during each event using Coshocton wheels (Brakensiek et al., 1979) modified to continuously deliver a flow-proportional sample of runoff water. Subsurface water samples were collected from developed springs that were downslope from the H-flumes. Water samples were vacuum filtered through 1.6-μm fiberglass filters and stored at 4 °C until analysis. Soil losses were calculated by measuring sediment concentrations in the runoff water and multiplying by the volume of runoff. Sediment concentrations were determined by evaporating 100 ml of runoff and weighing the sediment that remained. By weight, fecal material matter was assumed to be negligible. Similarly, nutrient losses were calculated by multiplying nutrient concentrations by the volume of runoff.

2.5. Chemical analyses

Water samples were analyzed for NH_4-N by an automated phenate method, and for NO_3-N plus NO_2-N by an automated Cd-reduction method (USEPA, 1979). Total N (Tot N) was determined by an automated phenate method after digestion in a block digestor modified to include NO_3- and NO_2-N (Schuman et al., 1973). Organic N (Org N) was obtained by difference between Tot N and Min N (mineral N) (the sum of NH_4-N and combined NO_3-N and NO_2-N).

3. Results and discussion

3.1. Vegetative cover

During the early years of these management systems, measurements of percent vegetative cover were made throughout the year. Even though actual % cover measurements were not made after the early years, frequent visual observations indicated that the measured trends for % cover were continuing. In the system where the cows were rotated in both growing and dormant seasons, percent cover remained at or near 100%. In the system with one area (WS 129) being a constant winter feeding area, there was considerable loss of vegetative cover during the dormant season (Fig. 2). There was a 40–80% loss of cover resulting from the constant occupancy during the over-wintering period. Another contributing factor is that the animal occupancy rate was 1497 and 1860 cow days ha^{-1} for the first nine dormant seasons and the last three dormant seasons, respectively (cow days ha^{-1} = number of cows × days in area/size of the area). The average length of winter occupancy in this area was 187 days. The herd size was 25 and 30 cows for the first 9 years and the last 3 years, respectively, of this study period. Thus, the average number of cows on a day of occupancy was 8 and 10 cows ha^{-1}, respectively. The occupancy rates for the watersheds in the rotational wintering system were 528 and 576 cow days ha^{-1} for WS 106 and WS 121, respectively, with approximately 14 cows ha^{-1} on a day of occupancy. Although the rotational wintering system had greater stocking rates per day, the periods of occupancy were much lower, ranging from 31 to 57 days. This information documented that the over-wintering period with constant animal occupancy created a system that was vulnerable to surface loss of water, sediment, and nutrients.

By keeping WS 129 (continuous wintering system) out of the first one or two summer grazing rotations, the percent cover returned to 100% and was generally above 90% from 1 June to 1 December (Fig. 2). During this 12-year period, when the cows were removed from the winter feeding area to begin their summer rotational grazing, it was an average of 43.4 days before they returned to WS 129. Once this pasture was in the summer rotation, the interval between grazing periods was usually 20–22 days.

Cumulative impacts of the winter feeding on the winter feeding area were also noticed. Bare and thin grass areas were reseeded in April 1980 and April 1983 with the whole area disked and reseeded in April 1986. To allow adequate time for the April 1983 seeding to grow, the length of the first return period was 62 days; it was over 50 days each of the next 3 years. The increase in herd size to 30 cows in 1983 also increased the pressure on the winter feeding area. Thus, the average 43.4 day length for the first return of cows was an average of 37.9 days for the first 8 years and 54.5 days for the last 4 years. The cows were in WS 129 for an average of 4.9 days during this first rotation; grazing times in the paddocks before and after this first period in WS 129 were 7.2 and 8.6 days, respectively. However, there was sufficient variation that the increases in the pre- and post-grazing periods were not statistically significant.

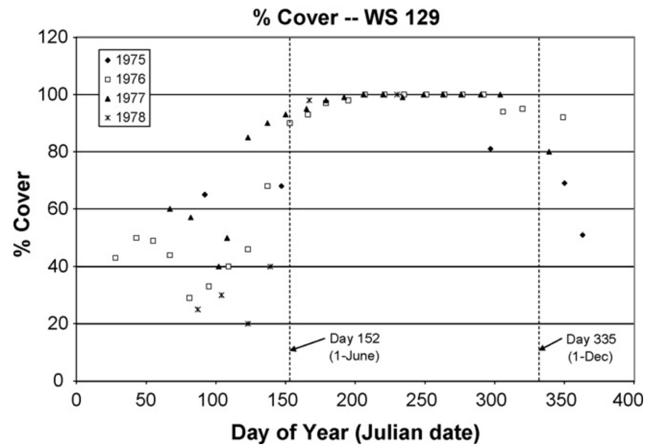

Fig. 2. Yearly percentage cover for the continuous winter feeding area (WS 129).

3.2. Surface runoff

The average number of runoff events in the continuous wintering area was similar during both the dormant and growing seasons, and the percentage of events ≥1 mm of runoff was similar for both seasons (Table 1). The average number of runoff events in the rotational wintering system was similar to the continuous wintering system during the dormant season but smaller during the growing season. The percentage of events ≥1 mm was only slightly lower than in the continuous wintering system during the dormant season but the percentage of runoff events ≥1 mm from the rotational system was more than a standard deviation unit lower than the continuous wintering system during the growing system. This could be the result of greater vegetative cover, and perhaps less compaction, to mitigate runoff event size.

Table 1
Average annual number of runoff events and average annual amount of runoff for all surface events and only the runoff events ≥1 mm for the 12-year study period, November 1974–October 1986.

	Dormant (May–October)			Growing (November–April)		
	Total	≥1 mm	≥1 mm (%)	Total	≥1 mm	≥1 mm (%)
Number of events						
Continuous						
WS 129	22.5	9.5	42.2 ± 14.0[a]	22.2	8.7	39.1 ± 20.6
Rotational						
WS 106	23.6	8.2	34.6 ± 15.0	18.7	2.9	15.6 ± 12.4
WS 121	24.6	9.2	37.6 ± 14.1	13.8	3.0	21.7 ± 17.1
Runoff (mm)						
Continuous						
WS 129	60.4 ± 26.9[a]	54.8	90.8	60.0 ± 39.3	57.9	96.6
Rotational						
WS 106	50.6 ± 26.6	47.2	93.6	17.4 ± 22.8	15.5	89.0
WS 121	61.9 ± 29.2	58.8	94.9	20.1 ± 32.9	18.8	94.0

[a] Standard deviation calculated using the seasonal percentages from the 12 years of the study period.

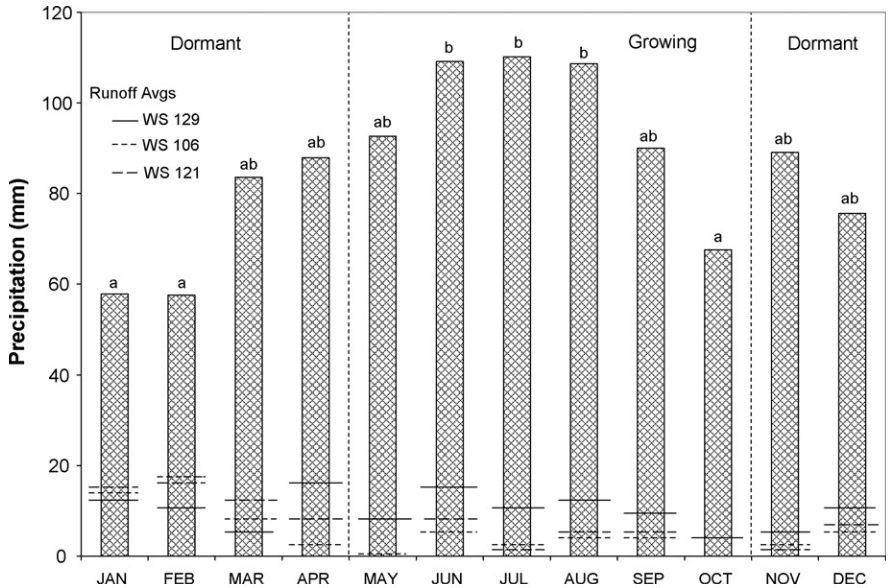

Fig. 3. Average monthly precipitation and surface runoff for the 12-year period of study, November 1974–October 1986. Dormant (November–April) and growing (May–October) precipitation seasonal averages were 452 and 578 mm, respectively. Precipitation columns headed by different lowercase letters differ significantly at $P < 0.05$.

Even though the number of runoff events ≥1 mm ranged from 15.6 to 42.2% of the total number of events, 89 to 96.6% of the runoff occurred in the ≥1 mm events (Table 1). The amount of runoff increased proportionally with the increase in the number of events ≥1 mm. Precipitation was greater during the growing seasons than the dormant seasons (Fig. 3). There was considerable variation within each month over the 12-year period so that LSD (5%) ANOVA showed limited significance.

Nevertheless, the amount of runoff was similar in both the dormant and growing seasons for the continuous wintering system, and the rotational wintering system had a similar amount of runoff during the dormant seasons for the 12-year period. The growing season runoff in the rotational wintering system was much lower than during the dormant season and was approximately 3% of the precipitation for the growing seasons. There was great year-to-year variation for a given month over the 12-year study period, especially during the growing season for the rotational wintering system (Table 1). The runoff from the continuous wintering system during the growing seasons and both wintering systems during the dormant seasons ranged from 11 to 14% of the precipitation received. This reduced average seasonal runoff during the growing season for the rotational wintering system is consistent with the fewer number of events ≥1 mm and would be influenced by the same factors, such as greater vegetative cover and potentially less compaction.

3.3. Sediment loss

Sediment was measured in each of the 217 runoff events ≥1 mm from WS 129 during the 12-year period from November 1974 through October 1986. The ≥1 mm events transported 97.4% of the total sediment loss during the study period from WS 129. Even though the majority of runoff events were <1 mm, there was no sediment transport event of importance among them. Late dormant/early growing seasons, i.e. March–June, were the times of greatest sediment loss (Fig. 4). March and April are during the time of low percentage cover (Fig. 2) and vegetative recovery. There were six events that exceeded 1 Mg ha^{-1} sediment loss (4 occurred in April, Table 2), and 14 events that exceeded 0.5 Mg ha^{-1} (8 occurred in April). These small numbers of events carried 39.4 and 57.7%, respectively, of the total sediment lost during the entire 12-year period. A few runoff events transporting the majority of the sediment lost over a multi-year period has also been reported for cropland (Edwards and Owens, 1991).

Sediment loss was quite variable (Fig. 5). Only 5 of the 12 years had months with total sediment loss greater than 1 Mg ha^{-1}. Nine of the 10 largest sediment transport events from the continuous wintering system (WS 129) were also the events with the largest sediment concentrations in runoff. The largest single event sediment loss was 2.8 Mg ha^{-1} on 27 June 1986, with 77.5 mm of causative rainfall and a peak precipitation intensity of 57.8 mm h^{-1} (Table 2). Also, 5.5 Mg ha^{-1} of sediment was lost in 3 events over 2 days on 8 and 9 April 1983 with 48 mm of causative rainfall. June vegetation would have been much more protective than April vegetation, and the peak precipitation intensities were lower in the April events. During this 12-year period, there were 15 rainfall events with peak intensities greater than 30 mm h^{-1}, 2 of which are shown in Table 2. All of them occurred in a growing season. Two growing season events caused the high sediment losses shown in Fig. 5 for May 1983 and June 1986. In the rotational wintering system (WS 106 and WS 121), there were no runoff events with sediment losses as great as 0.4 Mg ha^{-1}.

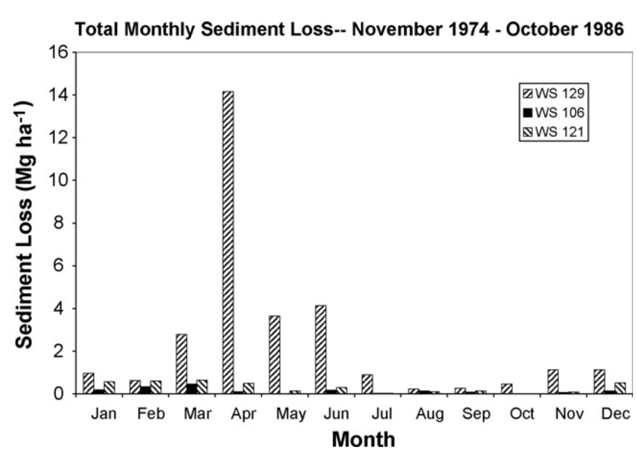

Fig. 4. Total sediment losses by month from the continuous winter feeding system (WS 129) and the rotational winter feeding system (WS 106 and WS 121); November 1974–October 1986.

Table 2
The ten largest sediment transport events from the continuous winter grazing system showing precipitation, runoff and peak precipitation intensity.

Date	Sediment loss ($Mg\ ha^{-1}$)	Precipitation (mm)	Surface runoff (mm)	Peak precipitation intensity ($mm\ h^{-1}$)
27 June 1986	2.84	77.5	28.9	57.8
9 April 1983 (1)	2.56	19.0	13.2	9.6
9 April 1983 (2)	2.30	16.0	13.2	29.4
8 April 1980	1.73	8.0	21.8	21.6
7 March 1980	1.65	11.9	17.2[a]	8.2
27 April 1983	1.26	16.8	4.0	23.0
2 May 1983	0.96	12.4	8.3	47.3
21 March 1984	0.84	35.1	8.2	7.6
8 April 1983	0.68	13.0	3.9	1.9
30 April 1975	0.68	28.4	14.5	23.0

[a] This runoff includes snowmelt.

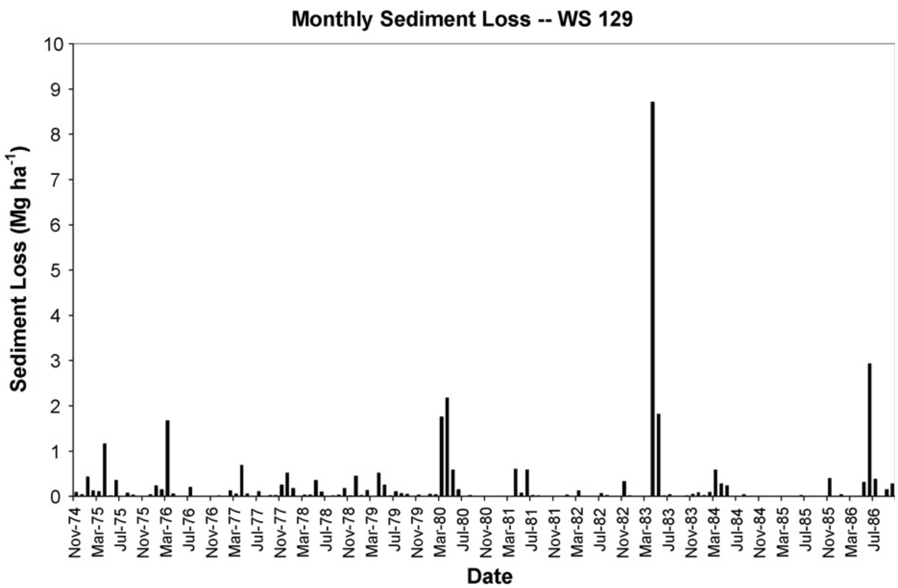

Fig. 5. Monthly sediment loss from the continuous wintering system (WS 129) for the 12-year period, November 1974–October 1986.

Total sediment loss for the 12-year study period was much less for the watersheds in the rotational wintering system (1.8 and 3.9 $Mg\ ha^{-1}$ for WS 106 and WS 121, respectively) than for the continuous wintering watershed (32.2 $Mg\ ha^{-1}$ for WS 129). Even though the sediment loss for the continuous wintering system was 8–18 times larger than from the watersheds in the rotational wintering system, the average annual sediment loss (<3 $Mg\ ha^{-1}$) was low compared with many rates of loss from cropped fields (Johnson et al., 1979; Laflen and Tabatabai, 1984; Ghidey and Alberts, 1998) and well within "soil loss tolerance values". A tolerance value is the maximum "annual amount of soil that could be lost without a decline in fertility, thereby maintaining crop productivity indefinitely" (Schertz and Nearing, 2002).

3.4. Nitrogen losses

Over 90% of the total N transported in surface runoff was in events ≥1 mm (Table 3). The continuous wintering system moved 1.9–2.5 times more Tot N than the watersheds in the rotational wintering system. When viewed in terms of N inputs, total N surface transport from the rotational wintering system was 3.0 and 3.8% from WS 106 and WS 121, respectively, with the annual

Table 3
Average annual N transported in surface runoff for all events and by season for the ≥1 mm runoff events for the period of November 1974–October 1986.

	Total N transport				Growing season ≥1 mm				Dormant season ≥1 mm			
	NO_3-N ($kg\ ha^{-1}$)	NH_4-N ($kg\ ha^{-1}$)	Org N ($kg\ ha^{-1}$)	Tot N ($kg\ ha^{-1}$)	NO_3-N ($kg\ ha^{-1}$)	NH_4-N ($kg\ ha^{-1}$)	Org N ($kg\ ha^{-1}$)	Tot N ($kg\ ha^{-1}$)	NO_3-N ($kg\ ha^{-1}$)	NH_4-N ($kg\ ha^{-1}$)	Org N ($kg\ ha^{-1}$)	Tot N ($kg\ ha^{-1}$)
Continuous												
WS 129	2.1	2.9	13.5	18.5	0.7	0.3	3.6	4.6	1.3	2.5	9.4	13.2[a]
% Tot N (≥1 mm)					14.4	6.7	78.9		9.6	18.9	71.5	
Rotational												
WS 106	1.8	2.8	2.9	7.5	0.5	0.1	0.4	1.0	1.0	2.5	2.3	5.8[b]
% Tot N (≥1 mm)					50.0	14.5	35.5		17.7	43.1	39.2	
WS 121	3.0	3.5	3.4	9.4	0.9	0.2	0.4	1.5	1.8	3.1	2.7	7.6[b]
% Tot N (≥1 mm)					57.6	11.4	31.0		23.8	40.6	35.6	

[a] The ≥1 mm runoff events for the continuous wintering system transported 92.0–96.8% of the annual N, depending on N form.
[b] The ≥1 mm runoff events for the rotational wintering system transported 84.9–93.8% of the annual N, depending on N form.

Table 4
Amount of N transported by the 10 largest transport events for each N form; transport of 10 largest events as percent of total; and number of 10 largest transport events occurring during the dormant season from November 1974 through October 1986.

	N transport from 10 largest events					Transport from 10 largest events as % of total				
	Flow (mm)	NO_3-N (kg ha^{-1})	NH_4-N (kg ha^{-1})	Org N (kg ha^{-1})	Tot N (kg ha^{-1})	Flow (%)	NO_3-N (%)	NH_4-N (%)	Org N (%)	Tot N (%)
Continuous										
WS 129	267 (1)[a]	9.9 (5)	16.8 (10)	69.9 (8)	82.8 (9)	18.5	39.2	47.6	42.6	37.2
Rotational										
WS 106	222 (8)	10.7 (8)	15.5 (10)	15.9 (10)	39.1 (9)	27.3	49.3	45.9	46.8	43.6
WS 121	562 (7)	17.2 (9)	22.3 (9)	21.0 (10)	52.0 (9)	55.9	47.5	53.0	51.1	43.6

[a] Values in parentheses are the number of the 10 largest events that occurred during dormant periods. These numbers are different for different forms of N because the forms of N do not necessarily move simultaneously, i.e. the top transport event for NO_3-N may not be the same as the top transport event for Org N.

224 kg N ha^{-1} rate and increased to 9.6 and 12.1%, respectively, based on precipitation inputs and N fixation from legumes (Owens et al., 1994). With nearly 300 kg N ha^{-1} brought into the continuous wintering system annually with hay, surface N transport out was 6.2% of the N inputs. Even with much greater N losses occurring in subsurface flow, the measured losses accounted for less than 50% of the inputs (Owens et al., 1994). This is consistent with other N balance studies on grasslands (Whitehead, 1995; Watson et al., 2000b).

In the continuous wintering system, over 70% of the N was transported in surface runoff as Org N, whereas less than 40% was moved as Org N from the rotational wintering watersheds. Much of this Org N may have originated from fecal material rather than plant residue. For a 12-year period after the 1974–1986 study period, the area for the continuous wintering system was no longer used for wintering livestock. Average annual Org N transport decreased from 13.5 to 0.3 kg ha^{-1}. This decrease occurred within 1 or 2 years of the management change, and the transport was fairly equally divided between growing and dormant seasons. This low rate of Org N transport was similar to the levels measured from the three summer-only grazing watersheds in the "medium fertility pasture system" (WS 102, WS 104, and WS 135). Very little information is available concerning Org N losses from grasslands, but the range of losses via subsurface drainage reported by Watson et al. (2000b) is between the losses from the continuous wintering system and the rotational wintering system. The Org N transport in this study was in surface runoff; none was measured in subsurface flow. Also, as noted by Watson et al. (2000b), Org N losses did not seem to be related to the level of fertilizer inputs.

Nitrogen loss as NO_3-N in surface runoff during the dormant season was <25% of the Tot N transport from the rotational wintering areas and <10% of the Tot N transport from the continuous wintering area, which lost 1.7–2.3 times more Tot N than the rotational wintering area during the dormant seasons. Inorganic N losses from the two winter systems were of similar magnitude, but the continuous wintering system had much greater Org N losses. This also indicates that fecal material may be the dominant source for Org N in surface runoff. The dormant seasons were the main periods for surface N transport; 74–85% of Tot N moved during the dormant seasons.

The 10 largest transport events, out of more than 270 events in each watershed (Table 1) transported 37–43% of the total N during the 12-year study period (Table 4). With the exception of NO_3-N transport in the continuous wintering area, more than 90% of the largest N transport events occurred during the dormant period.

With characterization of N transport via surface runoff, it is important to note that the majority of N transported moved via subsurface flow. The total annual subsurface N transport from the rotational wintering area during this study period ranged from 27 to 61 kg ha^{-1} (Owens et al., 1994), compared with annual surface runoff averages of 7.5 and 9.9 kg N ha^{-1} (Table 3). Likewise, the annual subsurface N transport from the continuous wintering area ranged from 28 to 60 kg ha^{-1} (Owens et al., 1982; Owens and Bonta, 2004), compared with 18.5 kg N ha^{-1} via surface losses (Table 3). As with surface losses, the dormant seasons were the periods for the greatest losses.

3.5. Nitrogen concentrations

Although inorganic N concentrations exceeded 20 mg L^{-1} for a few runoff events, the great majority of event concentrations were <5 mg L^{-1}, 80–94% for NO_3-N and 76–90% for NH_4-N (Table 5). Most of the runoff events with inorganic N concentrations >5 mg L^{-1} occurred during dormant seasons. Of the four growing season events with NO_3-N concentrations >10 mg L^{-1}, one of them occurred 4 days after N fertilizer application. The other three had no easy explanation.

Similar with inorganic N, over 80% of the runoff events had concentrations of Org N <5 mg L^{-1} in the rotational wintering system watersheds (WS 106 and WS 121), Table 5. However, in the continuous winter system watershed, WS 129, nearly 50% of the runoff events had Org N concentrations >5 mg L^{-1}. More of the events with Org-N concentrations >10 mg L^{-1} occurred during the growing seasons in the continuous wintering system than the rotational wintering system. This is consistent with the continuous wintering area needing a longer "recovery" period before summer grazing could begin.

It is interesting to note that there was better linear correlation between event concentration and transport for NO_3-N and Org N (correlation coefficients from 0.5 to 0.8) than between surface runoff and transport (correlation coefficients from 0.2 to 0.5)

Table 5
Distribution of NO_3-N, NH_4-N, and Org N concentrations for the wintering systems watersheds (WS 129, WS 106, and WS 121) for November 1974–October 1986.

	WS 129 (continuous)	WS 106 (rotational)	WS 121 (rotational)	Total
Number of events				
NO_3-N (mg L^{-1})				
0–5	204	115	117	436
>5–10	8 (6)[a]	13 (9)	20 (19)	41 (34)
>10–20	3 (1)	2 (2)	6 (6)	11 (9)
>20	2 (2)	2 (1)	4 (3)	8 (6)
NH_4-N (mg L^{-1})				
0–5	194	101	113	408
>5–10	10 (10)	18 (18)	13 (13)	41 (41)
>10–20	10 (9)	10 (9)	13 (13)	33 (31)
>20	3 (3)	3 (3)	8 (8)	14 (14)
Org N (mg L^{-1})				
0–5	114	107	120	341
>5–10	44	17	13 (10)	74
>10–20	29 (22)	3 (3)	9 (7)	41 (32)
>20–40	20 (12)	4 (4)	5 (5)	29 (21)
>40	10 (9)	1 (1)	0	11 (10)

[a] Numbers in parentheses are events that occurred during dormant seasons.

Table 6
Correlation coefficients for concentration vs. surface runoff, concentration vs. transport, and transport vs. surface runoff for Org N and NO_3-N for runoff events from November 1974 through October 1986.

Watershed	*n*	Concentration vs. surface runoff	Concentration vs. transport	Surface runoff vs. transport
Org N				
WS 129	217	0.032	0.777	0.367
WS 106	132	0.004	0.624	0.483
WS 121	147	0.046	0.563	0.503
NO_3-N				
WS 129	217	−0.062	0.804	0.186
WS 106	132	−0.097	0.603	0.291
WS 121	147	0.010	0.501	0.493

(Table 6.) No correlation was present between event concentration and surface runoff. This indicated that as event concentrations increased, transport of these N constituents also increased. Sometimes increased surface runoff was a prominent factor causing increased transport, but not always. Rarely, however, did increased concentrations occur with increased surface runoff.

4. Summary

Grazing systems have received an increasing amount of research attention to address a variety of objectives, but over-wintering of livestock has still received only limited research. Because pastures are more susceptible to damage during winter due to the dormancy of the vegetation and vulnerability of soils to compaction and erosion, environmental impacts of over-wintering livestock need to be assessed. To help address this issue, wintering aspects of two grazing systems were evaluated over a 12-year period in east central Ohio for vegetative cover, surface runoff, sediment loss, and surface N loss. One grazing system had a continuous wintering area, and the other had a rotational wintering area.

Vegetative cover in the continuous wintering area varied from year to year but decreased throughout the dormant period and frequently became less than 50% by late winter/early spring. There were no major changes in vegetative cover in the rotational wintering system. Averages of monthly runoff were greater from the continuous wintering system than the rotational wintering system in 9 out of 12 months, with the greatest difference being in April. Most of the runoff came off in a relatively small percentage of events, e.g. 89–96.6% of the runoff occurred in 15.6–42% of the events. Similarly, sediment losses were greater from the continuous wintering system with the greatest losses occurring in April. Of 217 runoff events in the 12-year study period from the continuous wintering system, the 10 largest sediment loss events carried nearly half of the total sediment lost (48.3%). Nevertheless, the soil losses were within "tolerance limits" for erosion. More total N was lost in surface runoff during the dormant season than during the growing season in both systems. Annual NO_3-N and NH_4-N losses were similar in both systems, but Org N losses were four times greater from the continuous wintering system than from the rotational wintering system.

Because of the management changes that occurred within each system over the 12-year period, direct comparison of the two systems is difficult. Nevertheless, the results of these evaluations indicate that a rotational wintering system will have less annual surface runoff, sediment loss, and Org N loss than a continuous wintering system. But for the two systems studied, the animal occupancy rate was much greater in the continuous wintering system than in the rotational wintering system. Thus, even though reduction of sediment and Org N favors the rotational wintering system, more land area per cow would be necessary. Other wintering systems need to be assessed as well as other factors such as soil compaction and buffer zones/filter strips between the occupied area and a stream.

References

Alderfer, R.B., Robinson, R.R., 1947. Runoff from pastures in relation to grazing intensity and soil compaction. J. Am. Soc. Agron. 39, 948–958.

Anger, M., Huging, H., Huth, C., Kuhbauch, W., 2002. Nitrate leaching from intensively and extensively grazed grassland measured with suction cup samplers and sampling of soil mineral-N. I. Influence of pasture management. J. Plant Nutr. Soil Sci. 165, 640–647.

Bauer, A., Cole, C.V., Black, A.L., 1987. Soil property comparison in virgin grasslands between grazed and nongrazed management systems. Soil Sci. Soc. Am. J. 51, 176–182.

Bilotta, G.S., Razier, R.E., Haygarth, P.M., 2007. The impacts of grazing animals on the quality of soils, vegetation, and surface waters in intensively managed grasslands. Adv. Agron. 94, 237–280.

Brakensiek, D.L., Osborn, H.B., Rawls, W.L., 1979. Field manual for research in agricultural hydrology. USDA AH224. U.S. Gov. Print. Office, Washington, DC.

Costin, A.B., 1980. Runoff and soil nutrient losses from and unimproved pasture at Ginninderra South Tablelands, New South Wales. Aust. J. Agric. Res. 31, 533–546.

Daniel, J.A., 2007. Late-summer infiltration as affected by cropping and grazing management of winter-wheat pastures. J. Soil Water Conserv. 62, 103–109.

Doran, J.W., Schepers, J.S., Swanson, N.P., 1981. Chemical and bacteriological quality of pasture runoff. J. Soil Water Conserv. 36, 166–171.

Drewry, J.J., Cameron, K.C., Buchan, G.D., 2008. Pasture yield and soil physical property responses to soil compaction from treading and grazing—a review. Aust. J. Soil Res. 46, 237–256.

Edwards, W.M., Owens, L.B., 1991. Large storm effects on total soil erosion. J. Soil Water Conserv. 46, 75–78.

Emmerich, W.E., Cox, J.R., 1994. Changes in surface runoff and sediment production after repeated rangeland burns. Soil Sci. Soc. Am. J. 58, 199–203.

Ghidey, H., Alberts, E.E., 1998. Runoff and soil losses as affected by corn and soybean tillage systems. J. Soil Water Conserv. 53, 64–70.

Hofmann, L., Ries, R.E., 1991. Relationship of soil and plant characteristics to erosion and runoff on pasture and range. J. Soil Water Conserv. 46, 143–147.

Johnson, H.P., Baker, J.L., Shrader, W.D., Laflen, J.M., 1979. Tillage system effects on sediment and nutrients in runoff from small watersheds. Trans. ASAE 22, 1110–1114.

Kelley, G.E., Edwards, W.M., Harrold, L.L., McGuinness, J.L., 1975. Soils of the North Appalachian Experimental Watershed. USDA-ARS Misc. Publ. 1296. U.S. Gov. Print. Office, Washington, DC.

Laflen, J.M., Tabatabai, M.A., 1984. Nitrogen and phosphorus losses from corn–soybean rotations as affected by tillage practices. Trans. ASAE 27, 58–63.

Lang, R.D., 1979. The effect of ground cover on surface runoff fro experimental plots. J. Soil Conserv. New South Wales 35, 108–114.

Marlow, C.B., 1988. Streambank stability and cattle grazing in southwestern Montana: a response to the viewpoint. J. Soil Water Conserv. 43, 206–207.

Marlow, C.B., Pogacnik, T.M., Quinsey, S.D., 1987. Streambank stability and cattle grazing in southwestern Montana. J. Soil Water Conserv. 42, 291–296.

McDowell, R.W., 2006. Phosphorus and sediment loss in a catchment with winter forage grazing of cropland by dairy cattle. J. Environ. Qual. 35, 575–583.

Owens, L.B., Bonta, J.V., 2004. Reduction of nitrate leaching with haying or grazing and omission of nitrogen fertilizer. J. Environ. Qual. 33, 1230–1237.

Owens, L.B., Edwards, W.M., Van Keuren, R.W., 1989. Sediment and nutrient losses from an unimproved, all-year grazed watershed. J. Environ. Qual. 18, 232–238.

Owens, L.B., Edwards, W.M., Van Keuren, R.W., 1992. Nitrate levels in shallow groundwater under pastures receiving ammonium nitrate or slow-release nitrogen fertilizer. J. Environ. Qual. 21, 607–613.

Owens, L.B., Edwards, W.M., Van Keuren, R.W., 1994. Groundwater nitrate levels under fertilized grass and grass-legume pastures. J. Environ. Qual. 23, 752–758.

Owens, L.B., Edwards, W.M., Van Keuren, R.W., 1997. Runoff and sediment losses resulting from winter feeding on pastures. J. Soil Water Conserv. 52, 194–197.

Owens, L.B., Shipitalo, M.J., 2006. Surface and subsurface phosphorus losses from fertilized pasture systems in Ohio. J. Environ. Qual. 35, 1101–1109.

Owens, L.B., Van Keuren, R.W., Edwards, W.M., 1982. Environmental effects of a medium-fertility 12-month pasture program. II. Nitrogen. J. Environ. Qual. 11, 241–246.

Owens, L.B., Van Keuren, R.W., Edwards, W.M., 1983. Nitrogen loss from a high-fertility, rotational pasture program. J. Environ. Qual. 12, 346–350.

Owens, L.B., Van Keuren, R.W., Edwards, W.M., 1998. Budgets of non-nitrogen nutrients in a high fertility pasture system. Agric. Ecosyst. Environ. 70, 7–18.

Owens, L.B., Van Keuren, R.W., Edwards, W.M., 2003. Non-nitrogen nutrient inputs and outputs for fertilized pastures in silt loam soils in four small Ohio watersheds. Agric. Ecosyst. Environ. 97, 117–130.

Renard, K.G., 1988. Streambank stability and cattle grazing in southwestern Montana: a viewpoint. J. Soil Water Conserv. 43, 204–206.

Ridley, A.M., Christy, B.P., White, R.E., McLean, T., Green, R., 2003. North-east Victoria SGS National Experiment site: water and nutrient losses from grazing systems on contrasting soil types and levels of inputs. Aust. J. Exp. Agric. 43, 799–815.

Ryden, J.C., Ball, R.R., Garwood, E.A., 1984. Nitrate leaching from grassland. Nature (London) 311, 50–53.

Schuman, G.E., Stanley, M.A., Knudsen, D., 1973. Automated total nitrogen analysis of soil and plant samples. Soil Sci. Soc. Am. Proc. 37, 480–481.

Sharpley, A.N., Syers, J.K., 1979. Loss of nitrogen and phosphorus in tile drainage as influenced by urea application and grazing animals. N.Z. J. Agric. Res. 22, 127–131.

Schertz, D.L., Nearing, M.A., 2002. Erosion tolerance/soil loss tolerance. In: Lal, R. (Ed.), Encyclopedia of Soil Science. Marcel Dekker, New York, NY, pp. 448–451.

Stout, W.L., Fales, S.L., Muller, L.D., Schnabel, R.R., Weaver, S.R., 2000. Water quality implications of nitrate leaching from intensively grazed pasture swards in the northeast US. Agric. Ecosyst. Environ. 77, 203–210.

U.S. Environmental Protection Agency, 1979. Methods for Chemical Analysis of Water and Wastes. USEPA, Cincinnati, OH.

Warren, S.D., Nevill, M.B., Blackburn, W.H., Garza, N.E., 1986. Soil response to trampling under intensive rotation grazing. Soil Sci. Soc. Am. J. 50, 1336–1341.

Watson, C.J., Jordan, C., Lennox, S.D., Smith, R.V., Steen, R.W.J., 2000a. Inorganic nitrogen in drainage water from grazed grassland in Northern Ireland. J. Environ. Qual. 29, 225–232.

Watson, C.J., Jordan, C., Lennox, S.D., Smith, R.V., Steen, R.W.J., 2000b. Organic nitrogen in drainage water from grassland in Northern Ireland. J. Environ. Qual. 29, 1233–1238.

Whitehead, D.C., 1995. Nitrogen balances in contrasting grassland systems. In: Whitehead, D.C. (Ed.), Grassland Nitrogen. CAB International, Wallingford, UK, pp. 285–297.

Zobisch, M.A., 1993. Erosion susceptibility and soil loss on grazing lands in semiarid and subhumid locations of Eastern Kenya. J. Soil Water Conserv. 48, 445–448.